AD-A093 814 AIR FORCE AEROSPACE MEDICAL RESEARCH LAB WRIGHT-PATT--ETC F/G 5/5
EFFECTS OF HEADGEAR AND VISUAL ANGLE ON HEAD ROTATION SPECTRAL --ETC(U)
1976 D SHIRACHI, D L MONK, J H BLACK

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFAMRL-TR-76-68	2. GOVT ACCESSION NO.: AD-A093814
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): EFFECTS OF HEADGEAR AND VISUAL ANGLE ON HEAD ROTATION SPECTRAL CHARACTERISTICS	5. TYPE OF REPORT & PERIOD COVERED: Technical Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): D.K. Shirachi, J.H. Black, Jr, D.L. Monk	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Air Force Aerospace Medical Research Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio 45433	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 62202F 7184-04-43
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: 1976
	13. NUMBER OF PAGES: 14
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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EFFECTS OF HEADGEAR AND VISUAL ANGLE ON HEAD ROTATION SPECTRAL CHARACTERISTICS

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SUMMARY

Dynamic characteristics of the unrestrained human head movement control system are measured as a function of headgear weight and size of the stimulus trajectory envelope. The coherence, gain and phase spectral characteristics are unaffected by variations in the weight of the helmet and associated head line-of-sight measurement hardware; however, a gain amplitude nonlinearity related to stimulus visual field size is shown to exist.

INTRODUCTION

Significant hardware developments during recent years now permit practical, remote measurement of an operator's head line-of-sight with good accuracy and reliability. The advent of this practical capability has stimulated numerous proposed applications of Visually Coupled Systems, control systems which are directed by natural head movements with feedback information displayed in the operator's visual

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field. The purpose of this investigation of head pursuit tracking was to provide dynamic performance data to aid in the evaluation of the head movement system as an active controller and to identify important design considerations in the future development of head line-of-sight measurement systems.

Several DoD agencies and NASA are seriously considering potential applications of head-aimed control systems for aircraft flight control, head slaved simulator displays, navigation and reconnaissance sensor control, and target designation. Chouet and Young [1] have shown that a head position measurement device can be used as an efficient means of controlling vehicular attitude, especially for three-axis manual control, and other investigations of Visually Coupled Systems [2] have demonstrated the feasibility of head-controlled sensors and weapon systems. Head line-of-sight measurements are also being considered for selection and control of aircraft cockpit information displays and as a means of providing accurate bearing to way points for precision updating of onboard navigation systems.

All these applications of head control take advantage of the operator's proprioceptive feedback and utilize the rapid, precise head movement coordination which is a natural physiological activity in man and is coupled to his perception of and reaction to his environment. The research reported herein describes the characteristics of unrestrained head movement as a function of headgear weight and angular size of the visual field in which the pursuit task occurs.

METHODS

Experimental Apparatus

A Honeywell Helmet-Mounted Sight (HMS) which measures the operator's helmet angular line-of-sight in real-time was used to observe dynamic head movements. The Honeywell HMS [3] computed head line-of-sight coordinates from information generated by scanning infrared light beams transmitted from fixed-coordinate "light fans" mounted beside the experimental subject and received by infrared detectors mounted on a helmet worn by the subject. An electronic computation unit provided analog voltages corresponding to the horizontal and vertical coordinates of the head line-of-sight. The following three helmet configurations weighing 4-1/4, 3 and 2 pounds respectively were used in the experiments: a Navy Model LG1065; a Phase I, lightweight prototype, Model LG1087; and a modified Air Force Model LG1063 with visor, oxygen mask recepticles and associated hardware removed to reduce weight.

The moving target stimuli for the head pursuit tracking were generated by projecting a laser beam directed by an X-Y mirror galvanometer system onto a vertical viewing screen which subtended a visual angle of $\pm 20^{\circ}$ in both vertical and horizontal axes. The vertical and horizontal inputs to the galvanometer system were

uncorrelated and consisted of band-limited, Gaussian noise with a half-power bandwidth of 3 Hz. The helmet weight experiments used a $\pm 10^{\circ}$ visual field as the stimulus projection envelope, and the angular field experiments used amplitudes of $\pm 5^{\circ}$, $\pm 10^{\circ}$ and $\pm 15^{\circ}$ for the stimulus field.

The helmet weight experiments were conducted on two experimental subjects; the angular field experiments were performed on three experimental subjects. For all of the experiments, one subject was trained and the other subjects were untrained. The angular field experiments were performed with both the 2 and 4-1/4 pound helmets; however, since the results were identical, only data for the 2 pound helmet is presented here.

DATA ANALYSIS

The data analysis method chosen for investigation of the head movement system dynamics was power spectral analysis [4, 5], and the frequency information of the spectral analysis permitted a comparison of the authors' data with those in the literature. Using power spectral analysis techniques, one may directly compute the system's linear, input-output transfer function and coherence function which is a quantitative measure of the credibility associated with the computed linear transfer function.

It is assumed that the measured output response, $x(t)$, is the sum of an input stimulus, $u(t)$, multiplied by the system transfer function, $h(t)$, plus an additive noise source, $n(t)$, which is uncorrelated with the input.

$$x(t) = h(t)\ u(t) + n(t)$$

$$E[n(t)\ u(t)] = 0; \qquad 0 \le t \le T$$

Performing a Fourier transformation of the input and output variables and converting to power spectra

$$G_{ux} = H\,G_{uu} + G_{nx}$$

where G_{uu} = auto-power spectrum of $u(t)$

G_{ux} = cross-power spectrum of $u(t)$ and $x(t)$

G_{nx} = cross-power spectrum of $n(t)$ and $x(t)$

$E[\ ]$ = expected value operator

Assuming that $n(t)$ is uncorrelated with $x(t)$, and $n(t)$ is zero mean, Gaussian noise, then the use of ensemble averaging for the auto- and cross-power spectra for many segments of frequency computations causes G_{nx} to approach zero. Therefore,

$$\overline{G}_{ux} = H\,\overline{G}_{uu}$$

and

$$H = \frac{\overline{G}_{ux}}{\overline{G}_{uu}}$$

where $\overline{G}$ denotes the ensemble average.

The coherence function, γ^2, is defined as

$$\gamma^2 = \frac{\overline{G}_{ux}^{\,2}}{\overline{G}_{uu}\,\overline{G}_{xx}}\,; \qquad 0 \le \gamma^2 \le 1.0$$

where G_{xx} = auto-power spectrum of $x(t)$.

The coherence function is the proportion of input power contained by the output power spectrum and is a quantitative measure of the linear causal relationship between the input and output of a system.

Input-output cross-correlations were computed to determine the time delay of the output response relative to a given input stimulus. The lag time corresponding to the maximum value of the cross-correlation function is considered as the time delay of the measured input-output relationship.

The following time responses were recorded: horizontal stimulus, vertical stimulus, horizontal head movement response and vertical head movement response. For each of the stimulus-response pairs, cross-correlation functions, coherence functions and transfer function gain and phase angle spectra were computed so that direct and cross-coupled characteristics of each coordinate axis could be determined.

RESULTS

Helmet Weight

Data recorded from the helmet weight experiments showed no appreciable

differences in the coherence, phase angle or gain characteristics when HMS helmet weight was increased. The spectral characteristics for two subjects are shown on Figures 1 through 6, and these curves show no appreciable differences between helmets of different weight.

Based upon the definition of half-power bandwidth which is the frequency region in which the input-output signal power transfer function remains above 0.5 of maximum signal transmissibility (Bendat and Piersol [4]) and forming an analogous definition for the coherence function where a coherence value of 0.5 is analogous to the half-power point, the bandwidth of the head movement system was found to be approximately 2.0 Hz.

The transfer function gain varied between 0.3 and 0.4 for horizontal movements and 1.0 and 1.5 for vertical movements (figures 3 and 4). One can easily observe that the vertical gain was much greater than the horizontal gain, and these results agree with those of Shirachi and Black [6].

The phase angle curves showed no differences as a function of increasing helmet weight (figures 5 and 6), and the phase angle was a linear function of frequency as determined by a linear least squares fit of the data points with a correlation coefficient greater than 0.98.

Visual Field Size

In contrast with the results for the helmet weight experiments, there was a significant effect of visual field size on the transfer function gain (figures 7, 8 and 9). An increase of visual field size produced sizeable increases of gain throughout the response bandwidth of the head movement system. It should also be noted that the vertical gains were always greater than the horizontal gains, just as in the helmet weight experiments. The $\pm 5^{\circ}$ stimulus envelope produced quite small gains in the region of 0.07 to 0.15 (horizontal) and 0.2 to 0.7 (vertical) and the $\pm 15^{\circ}$ envelope produced gains of 0.6 to 1.5 (horizontal) and 1.1 to 3.0 (vertical). These results indicate that an interaction exists between the transfer function gain and size of the stimulus visual field.

The coherence functions for the visual field experiments were similar to those for the helmet weight experiments. Stimulus amplitude appeared to have negligible effect on coherence (figure 10a).

The phase angle curves also showed no amplitude effects (figure 10b), and they were linear with frequency just as in the helmet weight experiments. However, the phase angles in the high frequency region near 1.5 Hz showed less phase lag than the phase curves for the helmet weight experiments.

CONCLUSIONS

The head movement system had previously been thought to exhibit linear behavior which can be modeled by a constant gain term in series with a time delay element (Shirachi and Black [6]). However, new experimental evidence which shows an amplitude-dependent transfer function gain relationship has been presented in this paper which appears to challenge the linear model of Shirachi and Black. The invariance of the coherence and phase angle characteristics with stimulus field size combined with an amplitude-dependent gain characteristic do not conform to the linear system model. It is not readily apparent what mechanism or mechanisms are operating to produce the amplitude-dependent behavior presented here. Transfer function gain may be influenced by head and eye interaction at small stimulus amplitudes. Another probable factor is target angular velocity which varies as a function of stimulus amplitude when the forcing function bandwidth is constant. However, future experimentation is necessary in order to provide sufficient data to explain the transfer function gain behavior.

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LIST OF FIGURES

COHERENCE FUNCTION

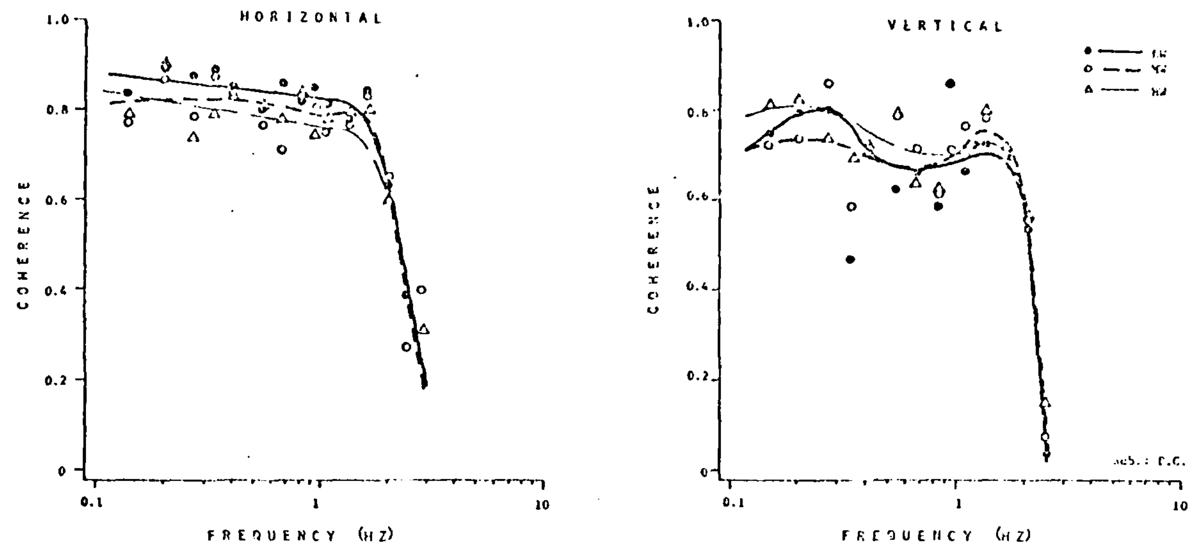

FIGURE 1

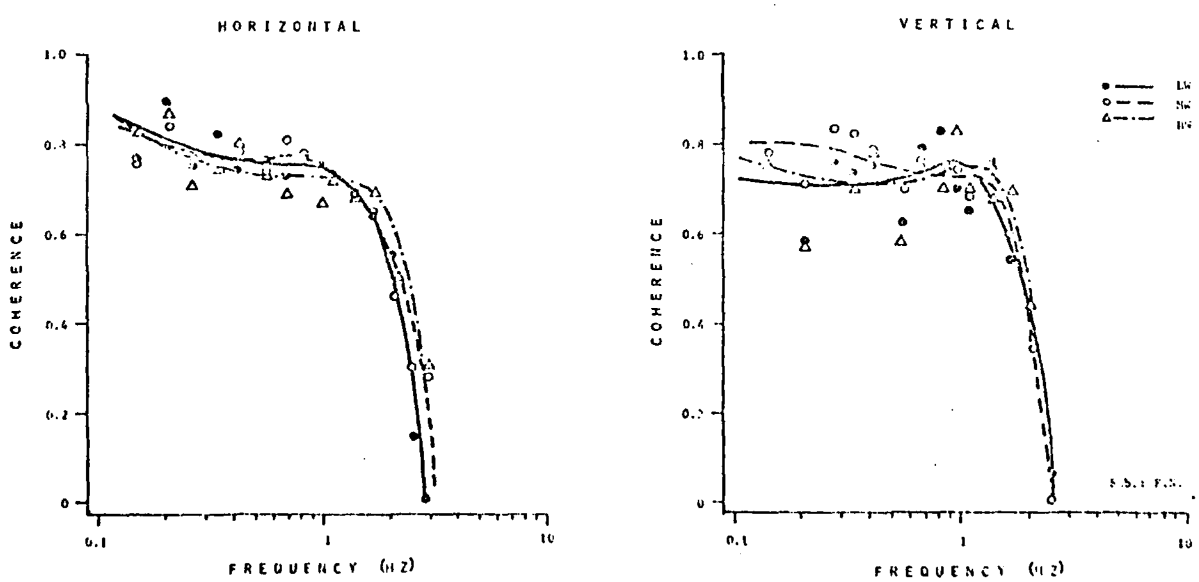

FIGURE 2

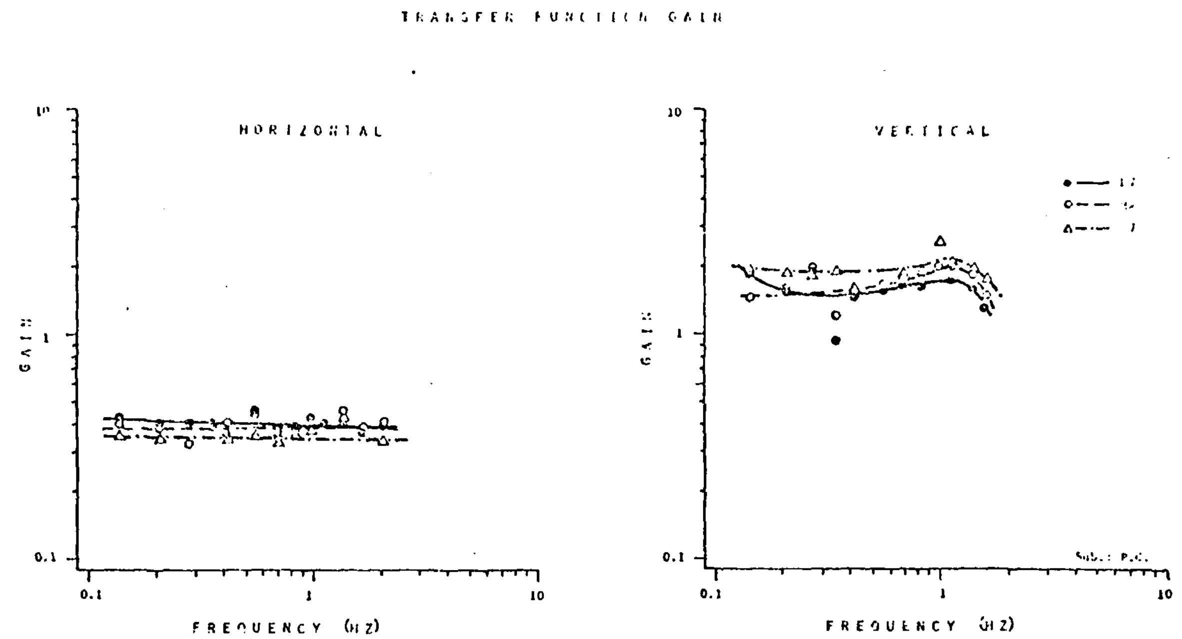

FIGURE 3

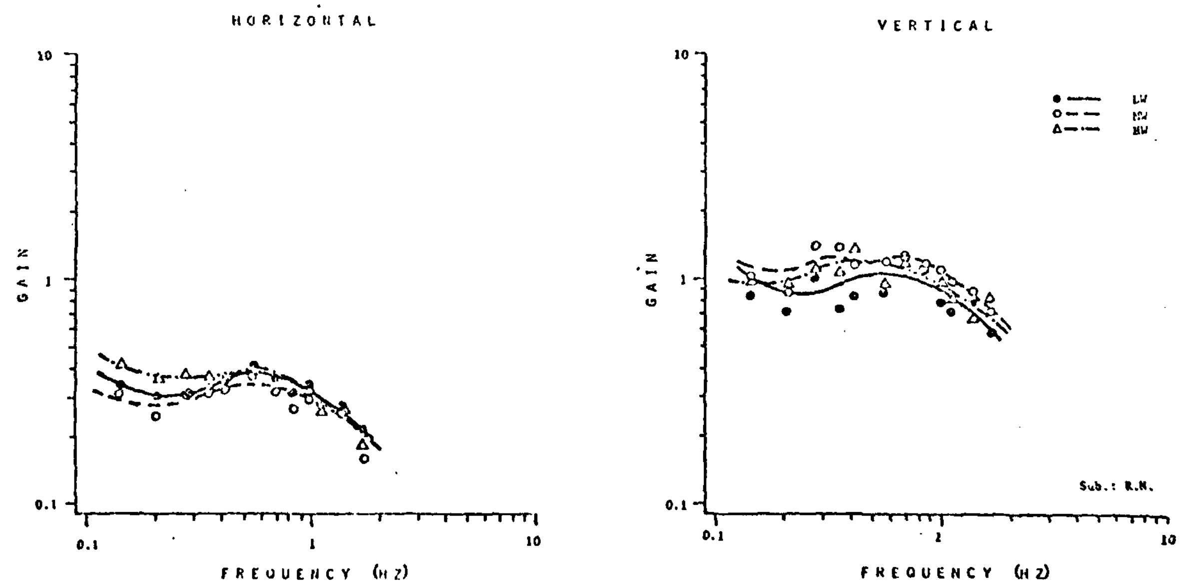

FIGURE 4

TRANSFER FUNCTION PHASE

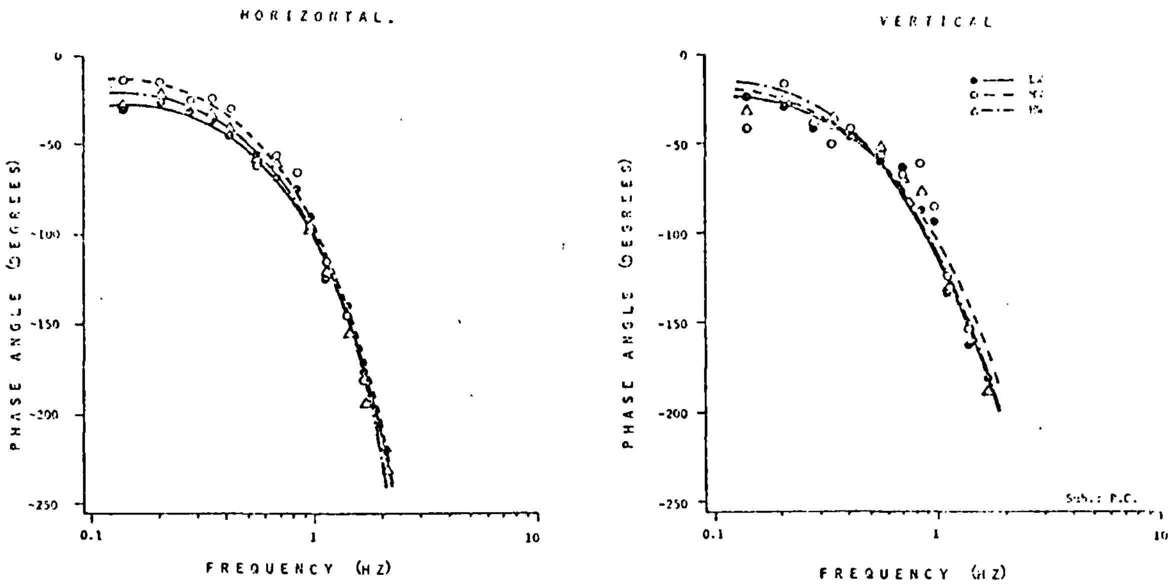

FIGURE 5

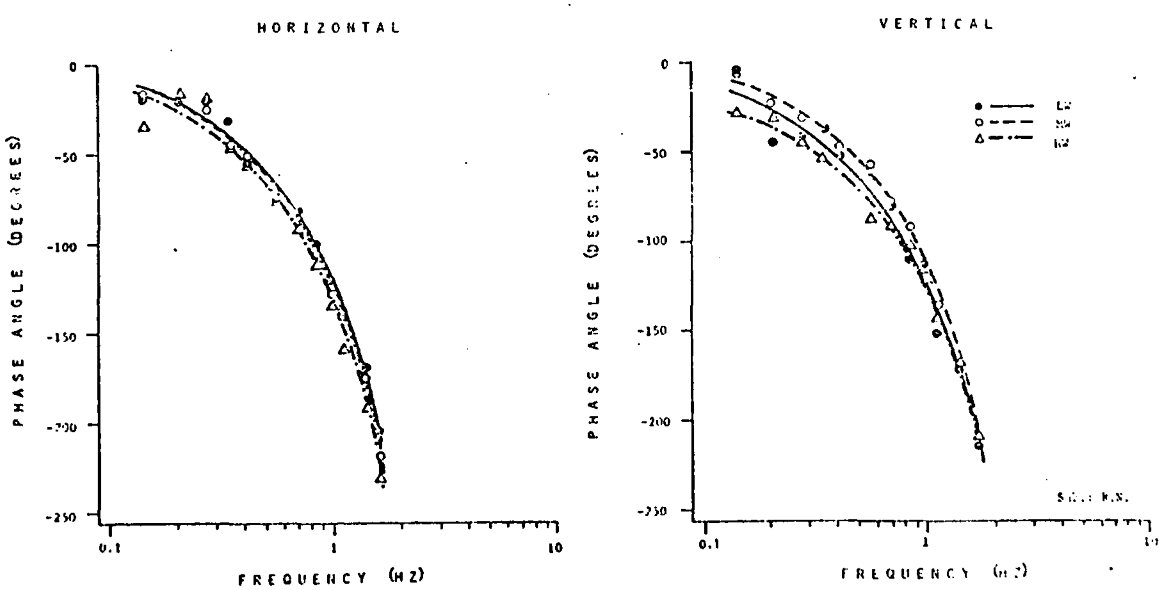

FIGURE 6

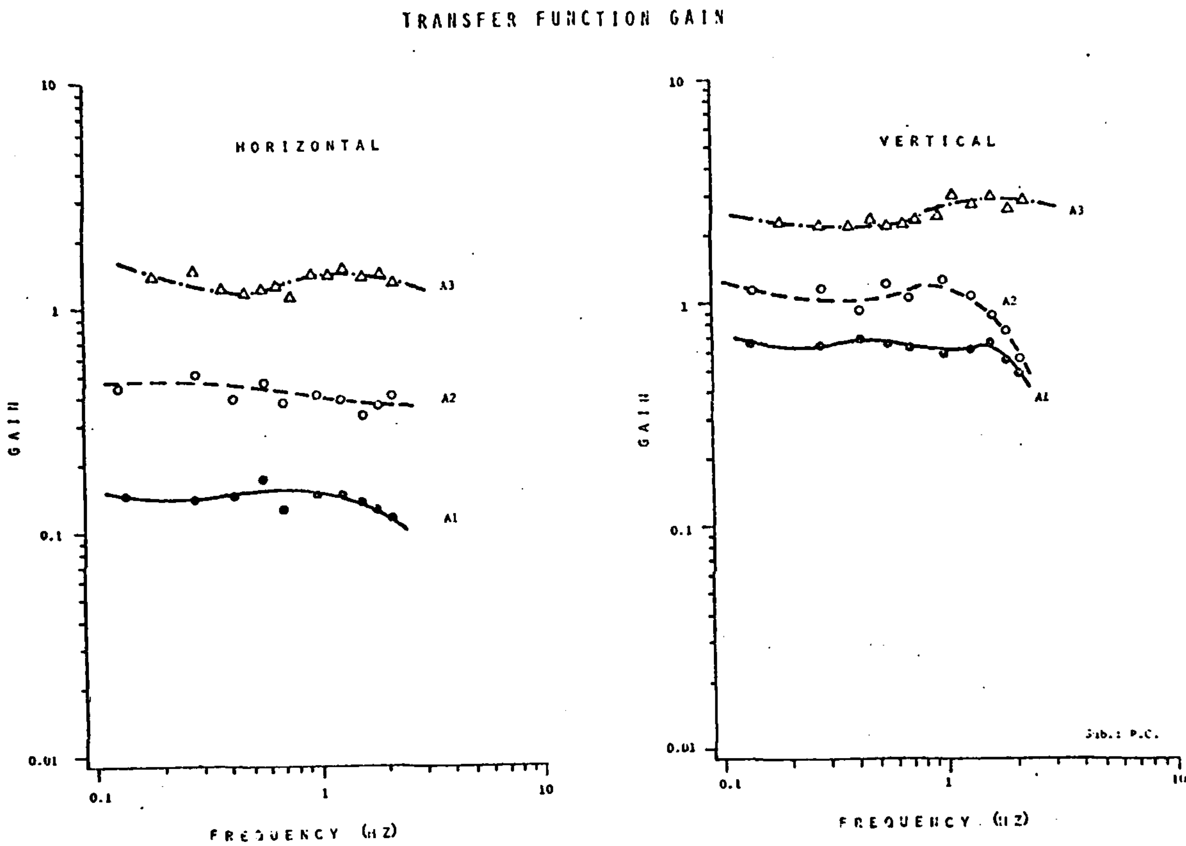
TRANSFER FUNCTION GAIN
HORIZONTAL
VERTICAL
GAIN
FREQUENCY (HZ)
A1
A2
A3
10
1
0.1
0.01

FIGURE 7

TRANSFER FUNCTION GAIN

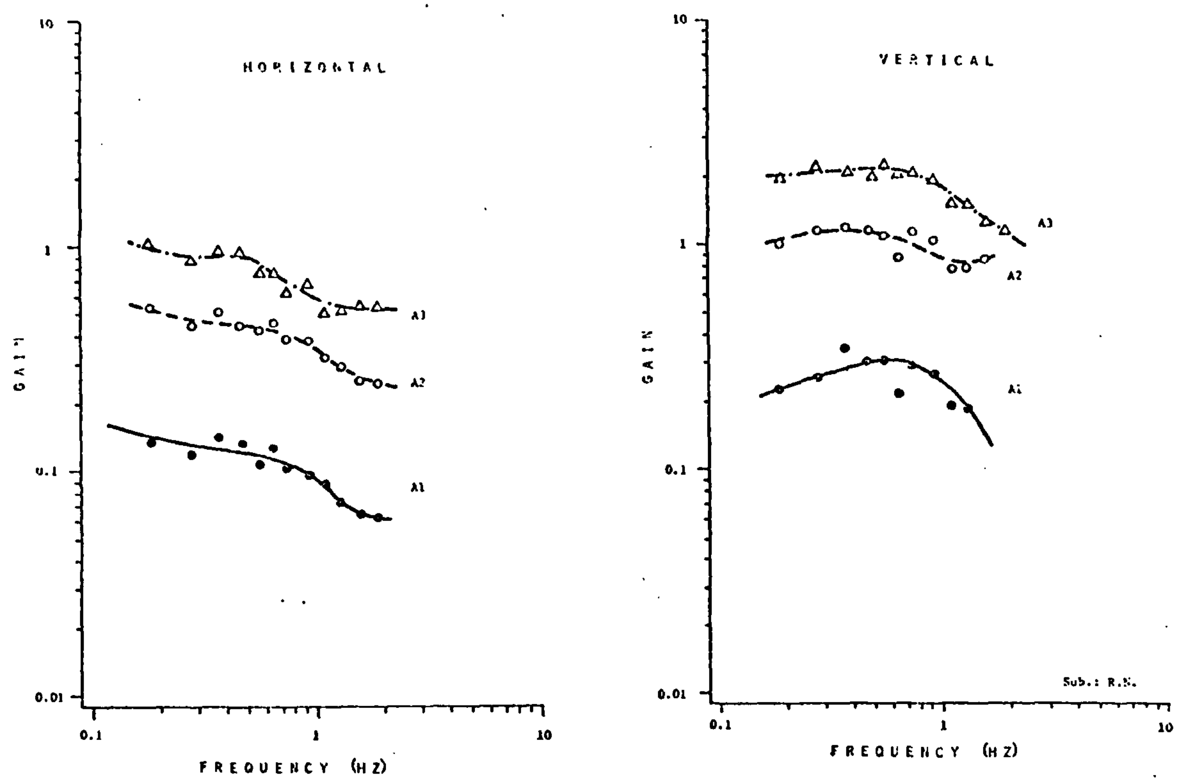

FIGURE 8

TRANSFER FUNCTION GAIN

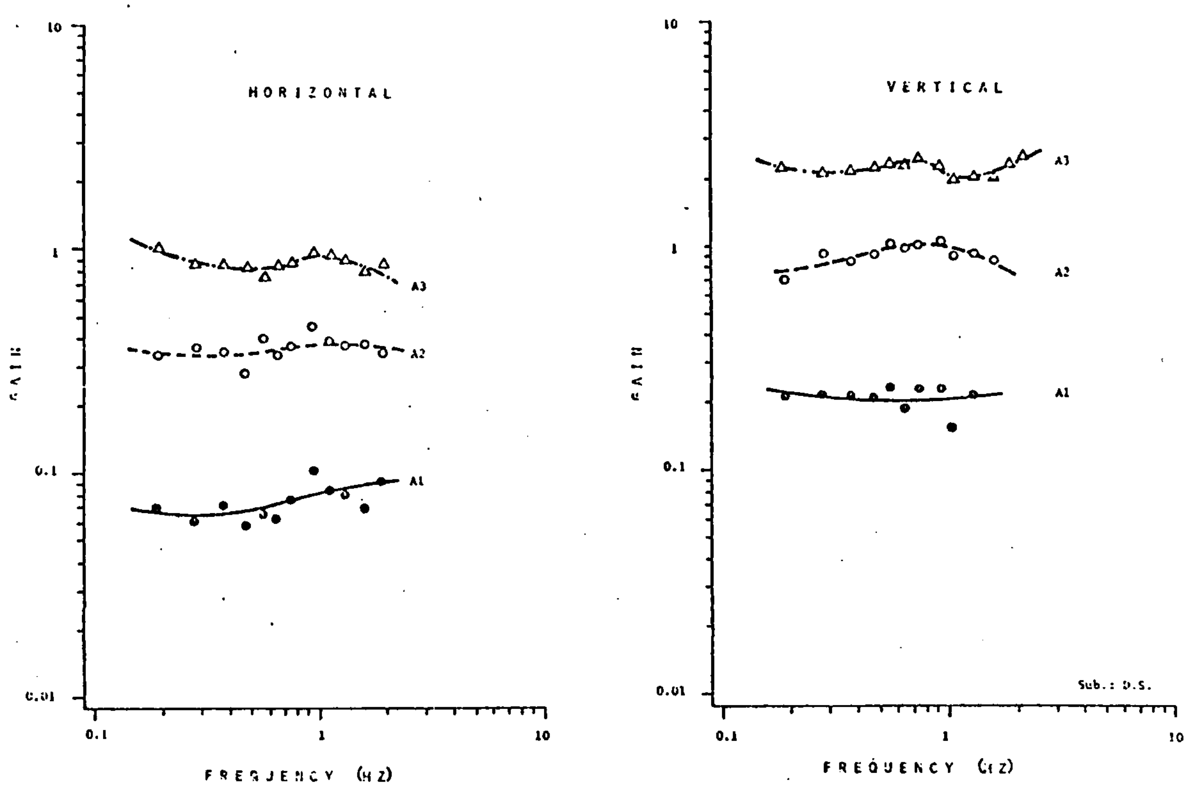

FIGURE 9

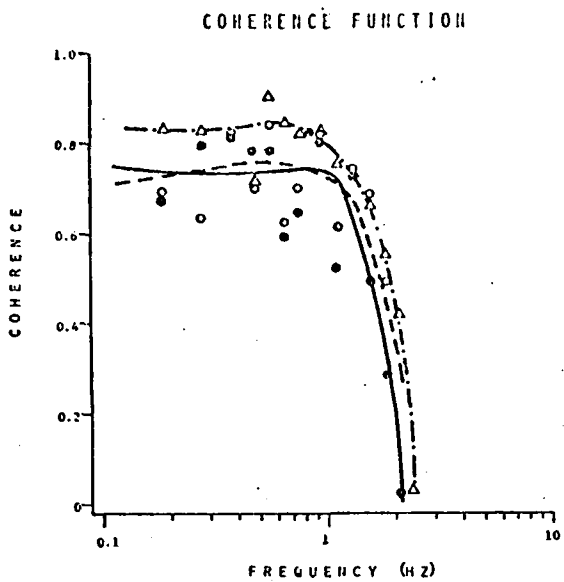

FIGURE 10a

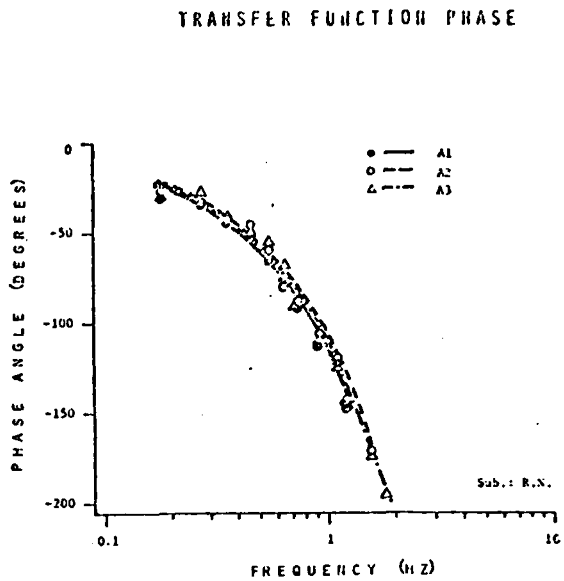

FIGURE 10b